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Materiel Test Procedure 3-1-004
Aberdeen Proving Ground

U. S. ARMY TEST AND EVALUATION COMMAND
BACKGROUND DOCUMENT

ARTILLERY RANGE AND BALLISTIC MATCH FIRINGS (INDIRECT FIRE)

1. INTRODUCTION

This test procedure provides general guidelines for conducting indirect-fire range and ballistic match firings of all types of artillery weapons (except direct-fire tank and antitank guns), recoilless rifles, and mortars.

NOTE: This MTP does not cover ballistic match tests for weapons employing a spotting round. Guidelines for range firing of direct-fire artillery are available in MTP 3-2-601. Ballistic match tests for weapons employing a spotting round are covered in MTP 4-2-605.

For each artillery weapon firing a specific type of projectile a firing table is required for use by the artilleryman in the field. This table is computed from ballistic data obtained by "range firing".

The same firing table can be used for two different projectile types if they are sufficiently similar in exterior ballistic properties, i.e., if they are "ballistically matched." Thus, if a standard round and a modified model of the round exhibit the characteristic of "ballistic match," a new firing table is not required. When the requirements for a new item of ammunition include ballistic match with an existing item, the engineering test plan includes criteria for evaluation of this characteristic.

Further background on the theoretical aspects of firing table computations and evaluation of ballistic match is found in paragraph 5.2.

2. TEST SETUP

2.1 SELECTION OF AMMUNITION

Unless otherwise specified, all projectiles must be from one accepted metal parts lot. When complete (fixed) rounds are furnished, they are disassembled and the projectile weights checked. If the weight marked on the projectile is incorrect, the weight marking is changed. The rounds are then reassembled. This requirement may be waived when the rounds furnished use projectiles that are already loaded and marked for certain weight zones. A sample of at least 10 of the projectiles is checked for conformity with applicable specifications and drawings (MTP 4-2-800). The following dimensions are determined:

a. Diameter of the bourrelet, two measurements taken 90 degrees apart.

b. Diameter of the rotating band, two measurements taken 90 degrees apart.

c. Width of the rotating band.

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d. Length of the ogive.
e. Length of the straight portion of the round below the rotating band.
f. Length and angle of the boattail.
g. Tightness of the rotating band.
h. Surface finish of the projectile.

If the required dimensions are checked with standard inspection gages, a statement that those dimensions are within the prescribed tolerances is sufficient. If any portion of a specific projectile does not fall within these tolerances, decision as to its rejection is made by the Firing Tables Branch (paragraph 5.2) and the remaining projectiles are measured. A projectile having a loose rotating band or other loose component is not used.

Since the projectile surface finish has a definite effect upon the exterior ballistics of the round, the above measurements are made without removal of the paint if the paint is smooth and has been uniformly applied. If any portion of the paint must be removed this fact is noted, making reference to the specific round numbers for which these projectiles were used.

2.2 SELECTION OF WEAPON

The range firing of ammunition for use with a specific system should be fired from that system when possible. Use of muzzle brakes and flash diffusers in the final system will require their use in range firing.

The tube selected must be in the first quarter of wear unless otherwise specified by the agency requesting the firing. It must be stargaged before and after the test. When the test is of sufficient duration, the test director may include additional gaging between phases.

2.3 LAYING OF WEAPON

To avoid movement of the weapon during the range firing test, the mount must be firmly seated. This is accomplished by the preliminary firing of a number of seating rounds, using a temporary line of fire. The final line (azimuth) of fire for the range firing program will then be established by survey (2.3.2 below).

2.3.1 Elevation

During range firing the weapon is set in elevation by means of a gunner's quadrant, using the breechblock of gunner's quadrant pads as the elevation reference plane. Since this is the method to be used in service by the field artillery, it assures consistency between the basic range firing data and service use of the published firing table.

The gunner's quadrant selected for use during the program is calibrated prior to the contemplated firings. Since the calibration correction depends largely on the wear at each quadrant setting, the instrument is calibrated for all elevations required in the program.

At each of the elevations specified by the test directive, a clinometer will be used to measure the difference between the angles of elevation of the breechblock gunner's quadrant pads and the tube centerline of the muzzle. This check will be made at all elevations to be used, both after the weapon has been firmly seated and after firing the program.

2.3.2 Azimuth

To maintain a weapon on the azimuth of the line of fire, the most accurate method is to align markings on the muzzle and breech with the line of fire by means of a surveyor's transit. The marks are scribed on the top of the muzzle and breech parallel to the axis of the bore. The transit is placed at the rear of the weapon, on a prolongation of the line of fire, and at a sufficient distance from the weapon to prevent the transit from being disturbed by the shock of firing. This method permits a final check on the weapon azimuth after the weapon has been loaded and elevated to the firing angle.

Boresighting is an alternate method used for maintaining the azimuth of fire when the top of the tube cannot be seen from the rear of the weapon because of obstructions on the carriage or between the weapon and transit positions. A boresight stake is placed in front of the weapon on the line of fire. The weapon is depressed and boresighted on this stake before each round. Much care must be taken to avoid moving the weapon off the line of fire while loading or when elevating the piece to the firing angle. The angle of cant of the trunnions is measured before and after each day's firing for corrections to the azimuth.

2.3.3 Direction of Final Adjustments

Regardless of the method used to maintain the weapon on proper azimith, the final adjustments for azimuth and elevation are always approached from the same direction. This eliminates, as much as possible, the effect of backlash in the gears of the weapon carriage or mount. The final azimuth setting is approached by traversing from left to right, and the final movement when setting the weapon in elevation is one of depression. The only exception to this procedure is when a nonstandard weapon might be used; that is, a tube with left-hand twist of rifling or a weapon that is extremely muzzle heavy, in which case the procedure may be reversed.

2.4 METEOROLOGICAL (METRO) REQUIREMENTS (MTP 3-1-003)

Firing tables are based on an adopted "standard atmosphere" (reference 5). Metro conditions on a given range firing date will usually differ from the standard atmosphere. For this reason metro data, both surface and aloft to 300 meters beyond the maximum ordinate, are taken each hour during the range firing test, starting before the first round is fired and ending after the last round is fired. Surface metro data, such as windspeed, wind direction, and temperature, require measurement at more frequent intervals.

It is inadvisable to conduct range firings when winds are excessively high or variable. Range firing should be discontinued when any one of the fol-

lowing conditions exists:

a. For maximum ordinates below 1500 meters (4921 feet):

1) Average surface windspeed exceeds 10 knots (11.5 miles per hour).
2) Surface wind gustiness exceeds 5 knots (5.8 miles per hour).

b. For maximum ordinates above 1500 meters (4921 feet):

1) Average surface windspeed exceeds 20 knots (23 miles per hour).
2) Windspeed at any discrete altitude between 300 meters (984 feet) and the maximum ordinate changes by more than 15 knots (17.3 miles per hour) from the windspeed observed at the same altitude one hour earlier.
3) Wind direction at any discrete altitude between 300 meters (984 feet) and the maximum ordinate changes by more than 800 mils (45°) from the wind direction observed at the same altitude one hour earlier. (If the windspeed at any discrete altitude is less than 5 knots (5.8 miles per hour), changes in wind direction may be disregarded and the range firing may be continued.)

The altitude of the "meteorological station" above mean low water (MLW) or mean sea level (MSL) should be included in the test report.

3. TEST DATA REQUIREMENTS

The following data are required during range firings and are reported in the published firing record:

a. For the weapon:

1) Complete nomenclature
2) Length of tube, defined as distance from trunnions to muzzle

b. For the projectile:

1) Complete nomenclature
2) Lot number

c. For the fuze:

1) Complete nomenclature
2) Lot number

d. For the propellant:

1) Complete nomenclature
2) Lot number

e. Impact data:

NOTE: Impact data are not usually supplied for projectiles designed for air burst application only. Time to burst, range to burst, and height of burst above MLW or above impact area are required for air burst firings.

1) Land: height of impact area above MLW or MSL
2) Water: tide readings every hour, bracketing times of firing

f. Metro data:

NOTE: Metro data are taken referenced to the line of fire.

1) Metro data aloft every hour, bracketing times of firing.
2) Surface metro data every hour, bracketing times of firing, and at more frequent intervals as deemed necessary by the test director.
3) Altitude of metro station above MLW or MSL.

g. Round-by-round data :

1) Date.
2) Time of firing.
3) Test round number and tube round number.
4) Azimuth of line of fire.
5) Height of trunnions above MLW.
6) Angle of elevation (clinometer), before and after each group.
7) Charge number.
8) Propellant temperature.
9) Fuze temperature (when applicable).
10) Projectile temperature (when applicable).
11) Projectile weight.
12) Slant distance from weapon muzzle to first velocity coil and between the first and second coils.
13) Coil time (projectile travel time between coils).
14) Time of flight to impact (or air burst, of 17 through 20 below).
15) Range to impact (or air burst, of 17 through 20 below).
16) Deflection.
17) Fuze setting (when applicable).
18) Time to air burst (when applicable).
19) Range to air burst (when applicable).
20) Height of air burst above MLW or above impact area (when applicable).

4. SAMPLE FIRING PROGRAMS

Examples of four typical firing table test plans for range and ballistic match firings (edited for display purposes) are shown in paragraphs 4.1 through 4.4. Test plan details may vary depending on the purpose of a test.

The test plan in paragraph 4.1 is unusual in that the test item is a "boosted" projectile, rocket propelled for a short distance for increased range. Problems of the powered flight portion of the trajectory and additional dispersion thus introduced require careful consideration in the test design stage to assure adequate data for the subsequent ballistic studies (MTP 3-2-821). Paragraph 4.2 is a special range firing test plan designed for evaluating the ballistic effect of nonuniformity of loading of a white phosphorous projectile. Paragraph 4.3 is a range firing program involving air bursts. For this type of range firing the individual air burst locations and flight times ("times to burst") are measured by means of cinetheodolites (MTP 5-1-031) and a fuze chronograph (MTP 4-2-808), respectively. Paragraph 4.4 is an example of a ballistic match range firing test plan. These test plans illustrate the variety of the test objectives and the need for carefully considered test plans.

4.1 RANGE FIRING PROGRAM FOR FIRING TABLE DATA FOR PROJECTILE, 105-MM, MX548

a. The following range firings are required:

Quadrant Elevation, degrees	Velocity Zone							
	1	2	3	4	5	6	7	7 w/Rocket
5		X		X		X		X
15	Xa		Xa		Xa		Xa	Xa
25		Xb	Xd	Xb		Xb		Xb
35	Xc		Xc		Xc		Xc	X
45	Xd	Xa		Xa	Xd	Xa	Xd	Xd
55	Xb	Xc	Xb	Xc	Xb	Xc	Xb	Xc
65		Xd		Xd		Xd		X
Maximum trailing angle	X		X		X		X	X
Total rounds: 750								

where,

X = 10 rounds conditioned to 70°F fired at the specified condition of quadrant elevation and velocity,

a = 10 rounds and propellant charges conditioned to 125°F fired alternately with those conditioned to 70°F,

b = 10 rounds and propellant charges conditioned to 0°F fired

alternately with those conditioned to 70°F,

c = 10 rounds and propellant charges conditioned to -40°F fired alternately with those conditioned to 70°F,

d = 10 rounds with a 1.5-lb. weight deviation from normal fired alternately with those of a normal weight, and maximum trailing angle: Determine the maximum angle at which the round will trail and then fire the remainder of the 10-round group for range data at that angle.

NOTE: The firing for maximum trailing angle should follow the 65° elevation firings.

b. The data to be collected are as follows:

1) General Information:

a) Weapon:

(1) Complete nomenclature.
(2) Length of tube, defined as distance from trunnions to muzzle.
(3) Description of emplacement (launcher should be tactically emplaced).

b) Projectile, fuze and propellant:

(1) Complete nomenclature.
(2) Lot number

c) Terminal event data

(1) Impact:

(a) Land - altitude of impact area above MLW or MSL.
(b) Water - tide readings every hour bracketing times of firing.

(2) Air burst:

(a) Time to burst.
(b) Range to burst.
(c) Altitude of burst above MLW or height above impact area.

2) Meteorological Information:

a) Metro data aloft each hour bracketing times of firing (winds should be oriented on the line of fire).

b) Altitude of metro station above MLW or MSL.

3) Round-By-Round Data:

a) Date of firing.
b) Time of firing.
c) Test and tube round numbers.
d) Azimuth of line of fire.
e) Altitude of trunnions above MLW.
f) Angle of elevation by clinometer, before and after each group.
g) Charge number.
h) Rocket on or off.
i) Propellant (rocket and charge) temperature.
j) Fuze temperature (when applicable).
k) Projectile weight without rocket propellant.
l) Projectile weight, center of gravity, transverse and axial moments of inertia with and without rocket propellant on a sampling of rounds.
m) Length and diameter on a sampling of rounds.
n) Slant distance from muzzle to first muzzle velocity coil and between first and second coils.
o) Coil time (ΔT for projectile travel between coils).
p) Position versus time radar records of each round fired are required; radial velocities of each round are desired.
q) Time of flight to terminal event.
r) Range to terminal event.
s) Deflection to terminal event.
t) Altitude of terminal event.
u) Fuze setting (when applicable).
v) Surface metro data.

c. A group of 50 rounds should be included to provide certain additional ballistic information that would not be available from the requested radar data. Jump information will be gathered and yaw card firings conducted. If camera instrumentation of sufficient quantity and quality were available, the round-by-round collection of data could be reduced; the cost of instrumenting relatively few rounds by camera would, however, probably exceed the cost of instrumenting each round by some radar device. This 50-round group is therefore needed to help span the gap in data that will result without the needed camera instrumentation.

4.2 RANGE FIRING PROGRAM FOR PROJECTILE, 175-MM, WP, XM510, WITH FUZE, PD, XM572

a. The following range firings are required:

1) With the propelling charges and projectiles conditioned to 70°F, fire 10-round groups of XM510 projectiles alternately with M437 projectiles at elevations of 20°, 45°, and 65°, in

each of the three velocity zones.

2) Fire a 10-round group of XM510 projectiles alternately with M437 projectiles at an elevation of 65° in each of the three velocity zones. For this firing the XM510 projectiles will be conditioned to 125°F for a period of time sufficient to liquefy the WP filler; the M437 projectiles will be conditioned to 125°F and the propelling charges to +70°F.

3) Fire 10-round groups of XM510 projectiles at an elevation of 65°, in zone 3 only, under the following conditions:

a) Condition the projectiles to a temperature to insure complete liquefaction of the WP filter. Place each projectile on its nose and allow it to cool so that the WP filler solidifies. Fire the projectile and propelling charge at +70°F.

b) Repeat the procedure in a above, except with each projectile placed on its base when cooling.

c) Repeat the procedure in a above, except with each projectile placed on its side when cooling.

b. Because of the type of filler contained in the XM510 projectile, it is imperative that the conditions of firing be as near to the stated conditions as possible. Under no circumstances should the conditioned rounds be allowed to become affected by the ambient surroundings. The time lapse from conditioning box to firing must be kept to a minimum, and each group of rounds should be fired in as short a period of time as possible.

c. Firings in zone 1 are to be conducted with propelling charge XM124 and in zones 2 and 3 with propelling charge M86E1 (single grain). This range firing program requires a total of 150 XM510 projectiles and 120 M437 projectiles.

d. Complete range data, including metro data aloft, are required for each group fired. Balloon runs for metro data should be made before the first round of the day is fired, at 1-hour intervals during the firings, and after the last round of the day has been fired. Elevation should be measured with a muzzle clinometer before and after each group is fired.

4.3 RANGE FIRING PROGRAM FOR FIRING TABLE DATA FOR PROJECTILE, 155-MM, ILLUMINATING, M118A1B1, WITH CHARGE, PROPELLING, XM119E4, USING HOWITZER, SP, M109.

a. The following range firings are required:

No. of Rounds	Elev.	Fuze Setting	Range to Burst	Height of Burst	Range to Impact
10	15°	18.0	7475	750	9800
10	25°	35.0	11600	750	12615
10	35°	48.1	13675	750	14325
10	45°	59.5	14435	750	14890
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b. Complete range data including metro data aloft are required. Condition all propellant to +70°F. The tube used in this test should be in the first quarter of wear.

4.4 BALLISTIC MATCH RANGE FIRING PROGRAM FOR COMPARISON OF PROJECTILE, 155-MM, SMOKE, M116E1 AND PROJECTILE, 155-MM, HE, M107

a. The following ballistic match range firings are required:

1) Fire, to ground impact, a 10-round group of M116E1 projectiles alternately with a 10-round group of M107 projectiles at a quadrant elevation of 45°.
2) All projectiles are to be in the standard weight zone (four squares). Fuze, MTSQ, M501A1 is to be used with the M116E1 projectiles, and Fuze, MTSQ, M500A1 is to be used with the M107 projectiles. All fuzes are to be set super-quick for ground impact.
3) All propellant should be conditioned to +70°F.

b. The tube used in this test should be in the first quarter of wear.
c. Complete range data including metro data aloft are required.

5. DATA REDUCTION AND PRESENTATION

5.1 FIRING TABLE DATA

Reduction of raw data to provide observed range, deflection, and time of flight, and reduction of radiosonde data to obtain the observed upper air metro-structure are performed by the proving ground. Subsequent processing to compute firing tables is by the Firing Tables Branch, U. S. Army Ballistic Research Laboratories.

5.2 TEST DATA ON BALLISTIC MATCH

Qualified personnel will reduce observed range data to standard conditions using the following procedures before statistical treatment is made for determination of ballistic match.

5.2.1 Range Firing and Computation of Firing Tables

While of great interest to theoretical ballisticians, a complete theory for the motion of a projectile in free flight is not directly applicable for the practical computation of data for firing tables. Practical trajectory computations have traditionally utilized simple differential equations that regard the projectile as a moving point mass (except when dealing with such gun-launched items as "boosted" projectiles), meeting air resistance that is a function of actual physical parameters such as the projectile's size and shape, its velocity relative to the air, the density and temperature of the air. Familiar equations of this type are (reference 4. ch. X, eq (14)):

$$\frac{dv_x}{dt} = \frac{\rho F \cdot u_x}{C}$$

$$\frac{dv_y}{dt} = \frac{\rho F \cdot u_y}{C} - g$$

$$\frac{dv_z}{dt} = \frac{\rho F \cdot u_z}{C} + \frac{Qu_x}{C_L} ,$$

in which

v = projectile velocity relative to the ground (i.e., relative to a fixed x, y, z system of rectangular coordinates having the gun muzzle as origin, and having the z-axis vertical and the x-axis in the vertical plane of fire).

u = velocity relative to the air (= v + wind)

ρ = air density

F = "drag function"

C = "ballistic coefficient"

Q = "drift function"

C_L = "drift coefficient"

Drag function and drift functions (tables of F and Q as a function of u) are available for an assortment of projectile shapes. Thus the best available tables of F and Q for a given shape projectile can be identified. Using experimental data obtained by range firing, the above (or comparable) equations can be solved by some process of mechanical integration for the projectile impact coordinates (along with impact angle, impact velocity, and time of flight). In this computation the gun quadrant elevation (corrected for jump), the observed muzzle velocity, the observed surface meteorological data obtained at the gun site, and the projectile weight comprise the initial conditions. The observed air structure (wind, density, and temperature as a function of y) can be introduced at appropriate intervals as the solution proceeds. If C and C_L are fortunately chosen, this first solution will produce impact coordinates X_ω, Z_ω that equal the corresponding observed impact coordinates; usually, however, the process must be repeated until, by successive approximations, satisfactory values for C and C_L have been established. The object, of course, is to find values of C and C_L that reproduce the observed range and deflection. This process must be repeated for the various programmed quadrant elevations and muzzle velocities so that suitable tables of C and C_L can be compiled for computing the basic firing table for standard conditions, the various tables

showing the effects of non-standard conditions, and other data such as standard deviation in range and deflection as a function of range. For a more detailed discussion, see reference 1, Chapter 10. Many considerations are involved in the computation of firing tables, as illustrated in Figure 1 (reference 1, chapter 3).

The above acquaints the reader with the traditional concepts and approach for the compilation of firing tables. Modified procedures appropriate for high-speed digital computers have been developed and are currently employed.

The Firing Tables Branch of the Ballistic Research Laboratories at Aberdeen Proving Ground has the responsibility for computing the firing tables and providing the test agency with range firing programs (test plans) designed for generating the ballistic data input for these computations. Range firing test plans are designed to optimize and relate the range firing operations and the subsequent firing table computations. The test agency may often employ data obtained primarily for range firing for other engineering test phases such as safety evaluation, extreme-temperature performance, and functioning evaluation.

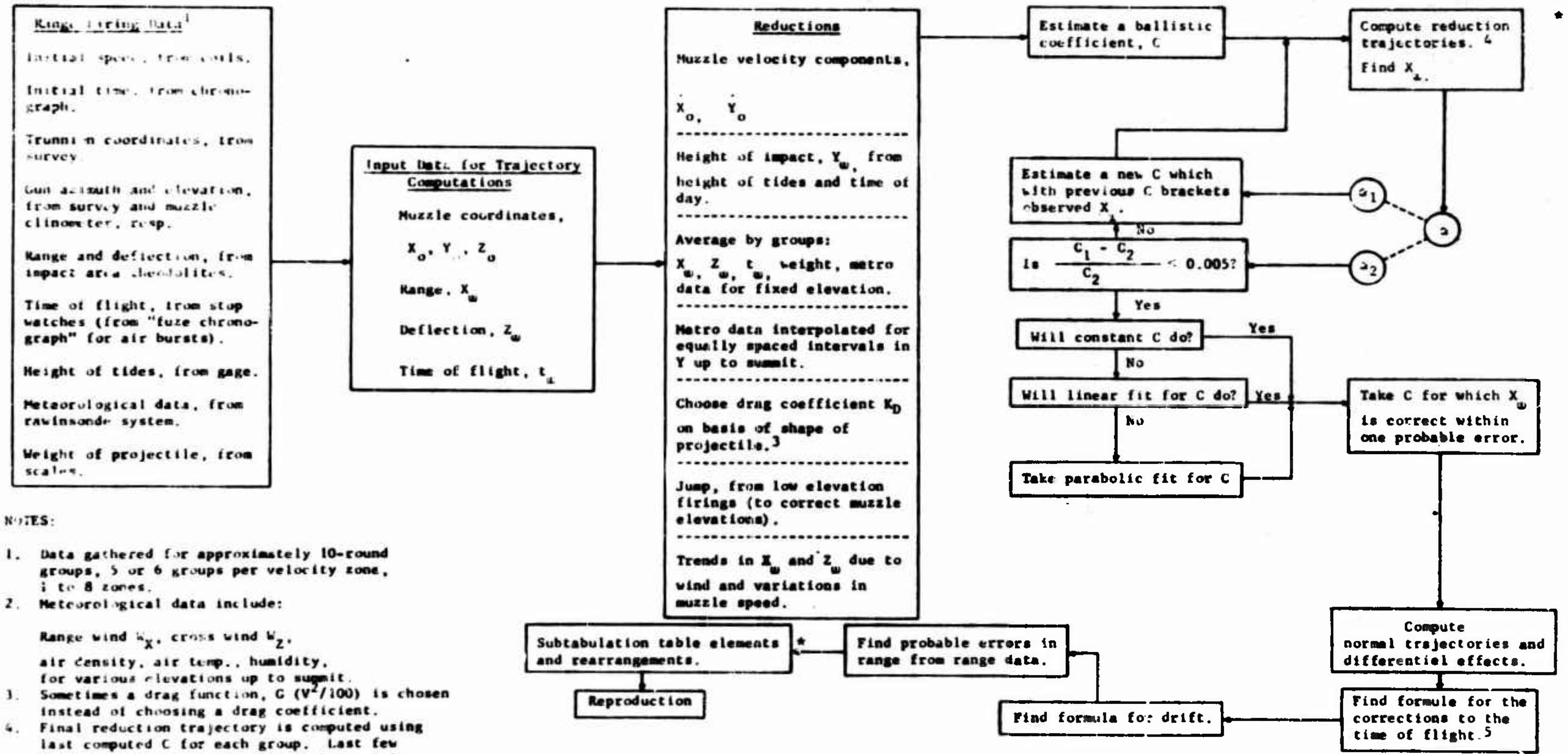
5.2.2 <u>Ballistic Match</u>

The degree to which two similar projectile types are ballistically matched is evidenced by the difference in their respective ballistic coefficients found from trajectory computations based on appropriate range firing data. The degree of ballistic match desired will depend on the projectile types involved, their functional uses, and the established weapon-projectile system impact accuracy and dispersion characteristics. If there has been a fuze modification to an accurate HE projectile, a high degree of ballistic match between the original and the modified projectile fuze system is desirable so that the original firing table can be used with confidence for the firing of either type. On the other hand, requirements for ballistic match between an HE projectile and an illuminating projectile might be less demanding.

Less range firing is required for evaluation of ballistic match than for computation of a complete firing table. Range firing programs for ballistic match testing sometimes involve only three or four quadrant elevations, with an appropriate number of rounds of each type fired alternately at each elevation. Complete range firing type data, including meteorological conditions aloft, are always required. As in the case of firing table ballistic data, the Firing Tables Branch of the Ballistic Research Laboratories is responsible for supplying ballistic match range firing test plans and for subsequent evaluation of ballistic match.

For reference in resolving ballistic match problems encountered in the planning and conduct of test operations a proving ground criterion for ballistic match follows.

The basis of the proving ground criterion of match between type A and type B rounds is a statistical test of significance. The criterion is



NOTES:

1. Data gathered for approximately 10-round groups, 5 or 6 groups per velocity zone, 1 to 8 zones.
2. Meteorological data include:

   Range wind W_X, cross wind W_Z,

   air density, air temp., humidity, for various elevations up to summit.
3. Sometimes a drag function, G ($V^2/100$) is chosen instead of choosing a drag coefficient.
4. Final reduction trajectory is computed using last computed C for each group. Last few reduction trajectories yield such special

   effects as $\frac{\partial X_\omega}{\partial C}$, $\frac{\partial X_\omega}{\partial V_o}$, $\frac{\partial X_\omega}{\partial \theta}$

   and parts of Z_ω due to rotation of earth and crosswind.
5. The t_ω correction formula is found before the last normal trajectories are computed.

*Using high-speed digital computing machines.

Figure 1: Flow Chart for Computation of Firing Tables

applied separately to ranges and to deflections. By means of a sample from each of the two populations of rounds, the intent is to determine whether the average range of type A differs from the average range of type B and whether the average deflections differ. If the statistical test reveals that a difference between ranges exists, the rounds are said to be mismatched in range; otherwise they are said to be matched in range. Similar statements are made for deflections. The level of significance (5 percent, 1 percent, etc.) is chosen with the understanding that the level is the probability of erroneously stating, as a result of each application of the test, that a mismatch exists when in fact type A and type B are perfectly matched.

Details sufficient to apply this criterion are given below. Additional discussion can be found in AMCP 706-110, paragraph 3-3.1, and more extensive tables (Student's t) can be found in AMCP 706-114, Table A-4. In addition to the criterion discussed herein, for some types of rounds the envisioned tactical usage may require a close match between the type A and type B rounds as regards mean weight and mean muzzle velocity.

a. The observed ranges for samples of type A and type B rounds are adjusted for variation of individual projectile weights from the standard weights and for variation of individual velocities from the standard velocities. All calculations on ranges, described below, are performed on the adjusted data. Adjustment of deflections is not normally performed. The formulas are expressed in terms of ranges but are equally applicable to deflections.

b. The following statistical quantities are calculated:

N_A = number of ranges of type A rounds

N_B = number of ranges of type B rounds

$\bar{R}_A = \dfrac{\sum R_A}{N_A}$ average range of type A rounds

$\bar{R}_B = \dfrac{\sum R_B}{N_B}$ average range of type B rounds

$S_A^2 = \dfrac{N_A \sum R_A^2 - \left(\sum R_A\right)^2}{N_A \, (N_A - 1)}$ variance of ranges of type A

$S_B^2 = \dfrac{N_B \sum R_B^2 - \left(\sum R_B\right)^2}{N_B \, (N_B - 1)}$ variance of ranges of type B

$S_P^2 = \dfrac{(N_A - 1)\, S_A^2 + (N_B - 1)\, S_B^2}{N_A + N_B - 2}$ weighted average of S_A^2 and S_B^2.

c. The following table is entered, using the selected significance level and $N_A + N_B - 2$, to obtain the proper value t. Then u is calculated:

$$u = t\, S_p \sqrt{\frac{N_A + N_B}{N_A\, N_B}}$$

Values of t

$N_A + N_B - 2$	Significance Level	
	5%	1%
5	2.571	4.032
6	2.447	3.707
7	2.365	3.499
8	2.306	3.355
9	2.262	3.250
10	2.228	3.169
12	2.179	3.055
14	2.145	2.977
16	2.120	2.921
18	2.101	2.878
20	2.086	2.845
25	2.060	2.787
30	2.042	2.750
40	2.021	2.704
60	2.000	2.660
100	1.984	2.626

d. If $|\bar{R}_A - \bar{R}_B| > u$, a significant difference has been found and it is stated that type A and type B are mismatched. If $|\bar{R}_A - \bar{R}_B| \leq u$, it is stated that type A and type B are matched.

e. In the above procedure a weighted average of the variances (S_p^2) was used. This is appropriate when the round-to-round dispersions of range for type A and type B rounds are essentially the same. A statistical test, the F-test, may be applied to $s_A{}^2$ and $s_B{}^2$ to judge whether the population dispersions can be considered as equal. If they cannot be considered equal, the procedure for making the t-test must be modified. AMCP 706-110, paragraph 3-3.1.2 describes the t-test procedure and paragraph 4-2.1 describes the F-test procedure.

f. The above procedure shows whether the observed $|\bar{R}_A - \bar{R}_B|$ is statistically significant. There remains the requirement to stipulate how large a statistically significant $|\bar{R}_A - \bar{R}_B|$ can be tolerated when both rounds are to

use the same firing table. The proving ground considers that rounds A and B show a statistically significant but tolerable degree of mismatch if

$$1.5\ S_P > |\bar{R}_A - \bar{R}_B| > u,$$

u being computed on the 5 percent significance level. A standard procedure for a specified weapon elevation and propelling charge is to fire 10 rounds of type A and 10 rounds of type B on a comparative basis, and to reduce the data as described above. At the 5-percent significance level $u = 2.101\ (S_P)\ (0.447) = 0.940\ S_P$. If $|\bar{R}_A - \bar{R}_B| \leq 0.940\ S_P$, rounds A and B are said to be matched for the weapon elevation and muzzle velocity specified. On the other hand, if $|\bar{R}_A - \bar{R}_B| > 0.940\ S_P$, there is substantial evidence that rounds A and B are mismatched to some degree. It can then be said that the observed degree of mismatch is acceptable if $|\bar{R}_A - \bar{R}_B|$ lies between the upper limit, $1.5\ S_P$, and the lower limit, $0.940\ S_P$; i.e., if $1.5\ S_P > |\bar{R}_A - \bar{R}_B| > 0.940\ S_P$.

When the firing program includes various firing elevations and muzzle velocity zones, both the magnitude and algebraic sign of the various observed $\bar{R}_A - \bar{R}_B$ values must be considered in the engineering judgment as to acceptability, taking into account also the technical characteristics and tactical uses of the respective rounds.

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13. ABSTRACT

This Background Document provides general testing information relative to conducting Range (indirect-fire) and Ballistic Match Firings of all types of Artillery Weapons, Recoilless Rifles, and Mortars. Direct-fire tank and anti-tank guns are not provided for.

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